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The Multicolor Panoramic Photometer-Polarimeter with high time resolution based on the PSD

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Abstract. Multicolor Panoramic Photometer-Polarimeter (MPPP) with a time resolution of 1 microsecond has been built based on a PSD and used at the 6-meter telescope in SAO (Russia). The device allows registration of the photon fluxes in four photometric bands simultaneously and finding values of 3 Stokes parameters. MPPP consists of Position-Sensitive Detector (PSD), acquisition MANIA-system, polarization unit and a set of dichroic filters. MPPP gives a possibility of detecting photons in 2 pupils with a size of 10 - 15 arc sec centered on the object and comparison star positions simultaneously. The first half of the object photon flux passes through the phase rotating plate and polarizer, and the second one through the polarizer alone. MPPP registers in each of the 4 filters four images of the object with different orientations of polarization plane and one image of a comparison star. It allows measuring instantaneous Stokes parameters. The main astrophysical problems to be solved with MPPP are as follows: investigation of optical pulsars; study of GRB phenomenon in the optical range; searching for single black holes; study of fast variability of X-ray binaries. As an illustration of MPPP use, the results of observations at the 6-meter telescope of Crab pulsar and soft gamma repeater are presented.

1. Introduction

For studying fast brightness variations of faint astrophysical objects it is necessary to use panoramic detectors of high time resolution. Detectors of such a type determine both coordinates and arrival time of each photon. The S/N ratio in this case reaches its maximum value at any seeing and sky background level. As a rule, the PSD which registers separate photons is created on the basis of the standard photocathode with low (relative to CCD matrices) quantum output, a set of microchannel plates and a position sensitive anode (Debur et al., 2002, this Conference). Some evident shortcomings areas follows:

– Low sensitivity (5-20%);
– Narrow dynamical range (limiting flux is 50-500 thousand photocounts/s);
– Low spatial resolution.

To minimize their influence when designing photometric detectors, it is desirable to use the following techniques:

– Simultaneous registration of emission in different spectrum regions (with different orientations of the polarization plane) with one PSD; this is achieved by using a set of dichroic light dividers;
– The registration of the object and comparison star images with their close neighbourhood (10”- 15”) instead of 1’-2’;
– Use of antireflecting field reducers varying the scale to 0”.2 - 0”.3 per element of resolution. The principles mentioned above form a foundation for construction of panoramic photometer- polarimeter for the 6-m telescope.

Even in spite of existence of more sensitive deteoctors like CCD, Postition-Sensitive Detector still has its own applications. It may be used for study of fast variability (with up to several microseconds resolution) of faint sources (for example it is ibpossible to analyse 19^m star variability using CCD with 1 count per pixel read-out noise). Comparison with cryogenic detectors developed now also shows that their are much more expensive and diffucult to use and provide much worse quantum efficiency.

2. Peculiarities of the optical scheme

Panoramic photometer-polarimeter registers only the light fluxes of the object under study and of the comparison star with their close vicinities, Fig.1. The light beam from the object is decomposed by the polarization unit into 4 components with different orientations of the polarization plane. The light beams from the object and comparison star pass through the set of dichroic filters and are registered with two PSD, one of which is optimized for the blue and the other for the red regions of the visible spectrum. As a result, each beam can be registered in four color bands U, B, V, R. For identification of the object

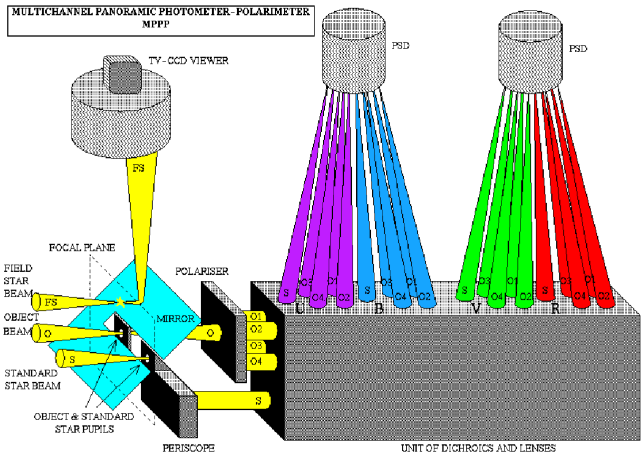

Fig. 1. General view of the optical layout.

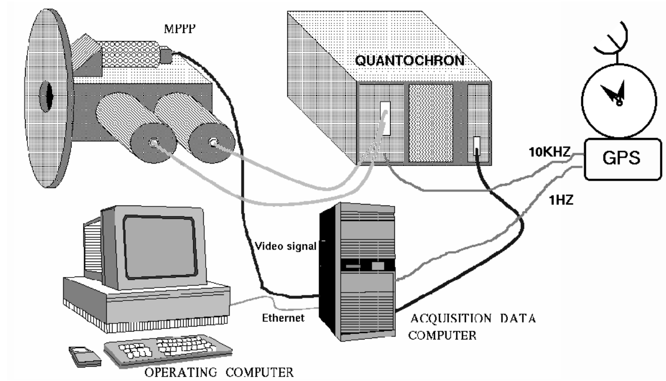

Fig. 2. The data acquisition complex.

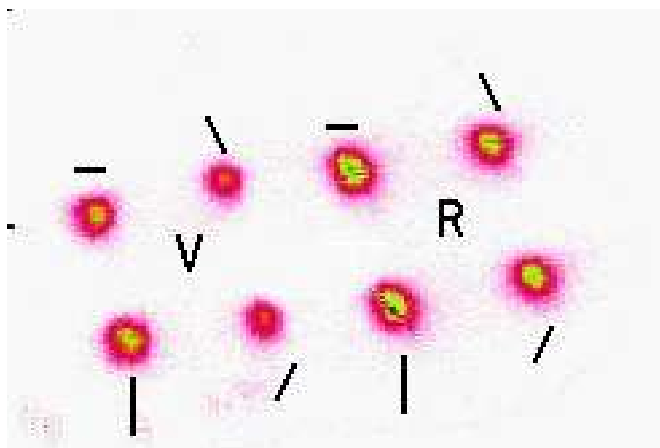

Fig. 3. Multimode image of the standard star in the color bands B, V and 4 orientations of the polarization plane.

being studied and precise setting it on the data registration channel, we employ the stellar field viewing based on a TV CCD camera which enables image acquisition on its matrix and fulfilling a sufficiently deep survey of the selected sky area. Such a scheme obviates the problem of registration of an excess flux of quanta and allows fulfilment of a multi-mode analysis of the fast-variable source emission.

3. Data registration

The photometer-polarimeter operates as part of the acquisition complex incorporating also a device for receiving photocount flux codes, a computer for control and data acquisition, which is located in the local net with the computer of the astronomer- operator. The functional diagram of the photometrical complex is shown in Fig. 2. The flux of photocounts from the PSD must be transferred to the computer data storage in the form it is received by the detector, as counts of registration time of all the quanta and their coordinates, the rate of count arriving must be up to 100 000 quants/s. For this purpose, we use the time-code converter Quantochron [1]. Primarily it was designed for registration of the data flows which have a 16-bit coordinate field (265x256 elements). The application of the PSD with a quadrant collector and the use of 10-bits ADC demanded extension of capacity up to 40 bits, this is why as a temporal measure we use a multiplexor which disconnects each arriving 40-bits photocount into three sequential messages: 8, 16 and 16 bits. The 8 bits in the first message are used for auxiliary information. The data obtained are stored and transferred by the 100mb Ethernet from the data acquisition computer to the control computer and then they are written on magnetic disks and then on CDROM. Storage of all primary data on the measured charges of each photocount allows a deeper analysis of data flow as to the presence and compensation for the instrumental effects.

4. Analysis methods

Observational data files are used, first of all, for obtaining images supplied to the detector cathode by the optical system of the photometer-polarimeter. As an example, in Fig. 3 we show the field of the detector with the standard star located on it in two-colour bands and four polarizations.

The quantum fluxes from the star in every position which are received with the PSD are subjected to temporal analysis for studying the processes occurring on the astrophysical object under study. Prior to the procedure of temporal analysis we improve the quality of the image produced by the astronomical optics and improve the S/N ratio by means of determination of coordinate variations of the integral center of the comparison star image on the detector and adaptive adjusting of the current location of the area for photocount flux selection, fig. 4.

We use the methods of search for stochastic variability in the range from microseconds to the exposure duration [2]. As example in fig. 5 is shown result of search for stochastic brightness variability of soft gamma repeater SGR 1806-20 [3]. So we search for and analyse periodical variability different astrophysical objects, for example, optical pulsars. In fig.6 we demonstrate the images of the

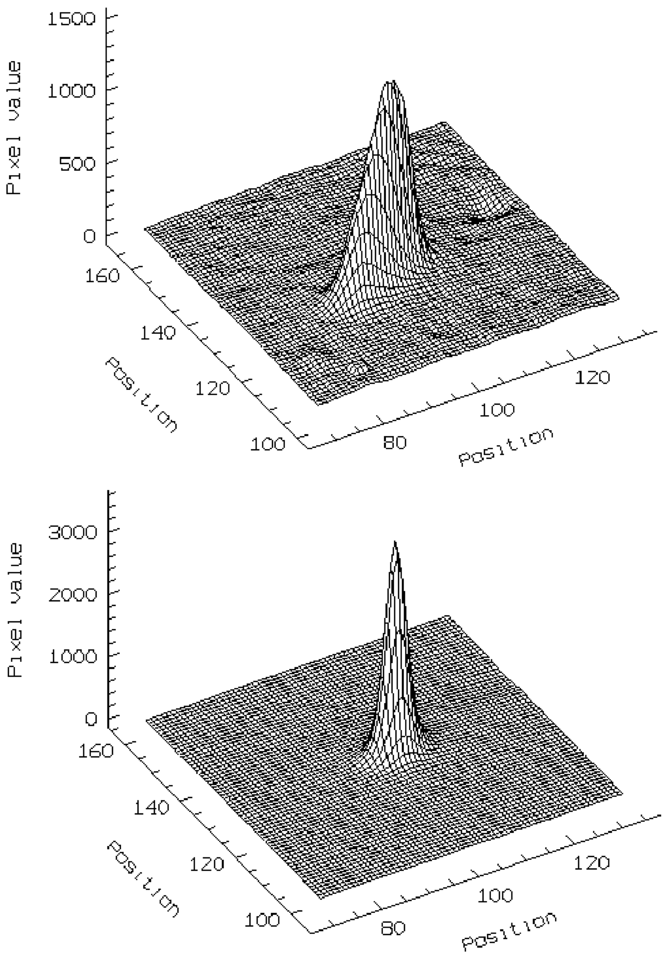

Fig. 4. Improvement of stars seeing and signal/noise ratio by the deconvolution procedure.

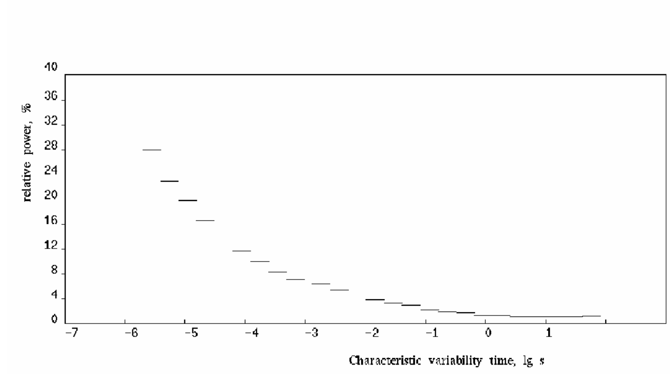

Fig. 5. Upper limits of the variable power component relative to a background level of soft gamma repeater SGR 1806-20. Restrictions correspond to stochastical triangle-like flares with a filling factor of 0.1 and a confidential probability of 99%. They will be 3 and $3 \cdot 10^3$ times lower for the filling factors 10^{-2} and 10^{-6}, respectively.

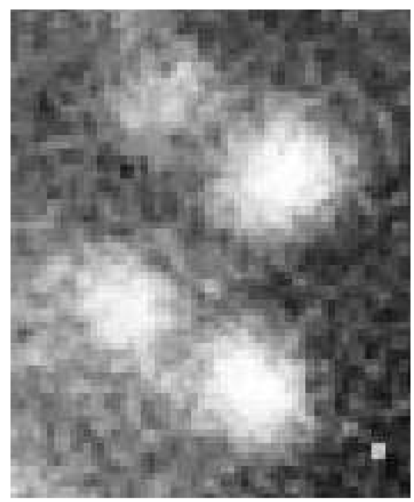

Fig. 6. Images of Crab pulsar (left) and standart star (right) in 2 orientations of the polarisation plane.

Crab pulsar and star-neighbour splited by polariser. Their phase- resolved images and the Crab pulsar folded light curve with a time resolution of 30 mcs are shown in fig. 5.

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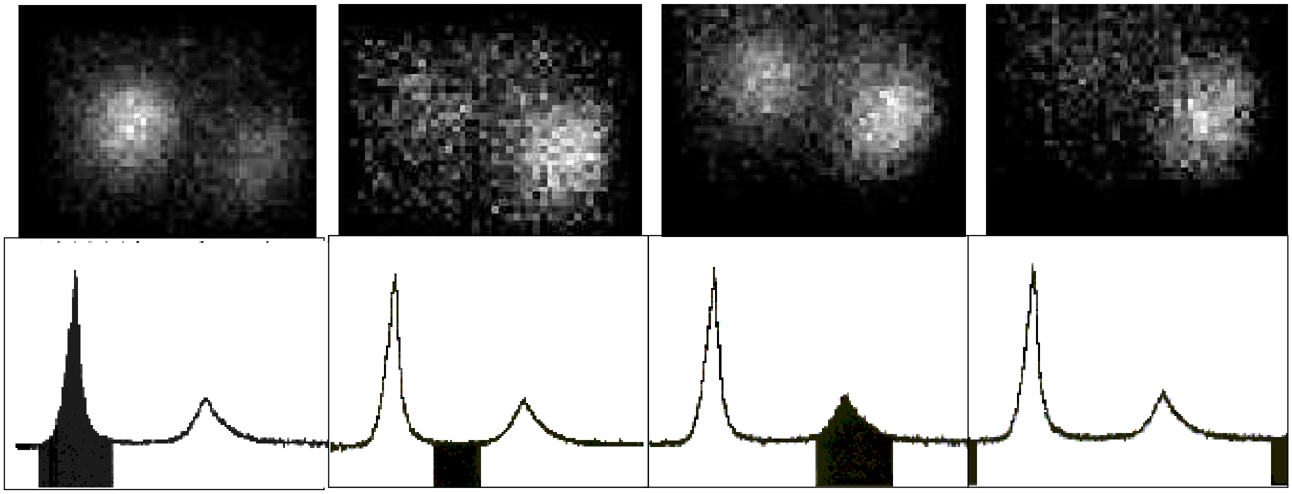

Fig. 7. Phase-resolved two dimension photometry of the inner Crab nebula in the B band, taking within radius of 50 pixels, the pulsar being center star. The location of each phase region is indicated in the light curve obtained from a radius of 15 pixels from Crab centroid, with the accompanying photometric image